



Title of Investigation:

Low-Outgassing Robust Micropattern Detectors

Principal Investigator:

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Other In-house Members of Team:

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Other External Collaborators:

None

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

\$0

Funding Authorized for FY 2005:

\$60,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: \$60,000

Status of Investigation at End of FY 2005:

Completed in FY 2005

Purpose of Investigation:

The purpose of this investigation was to develop the ability to produce micropattern detectors specifically tailored for space-flight applications. The micropattern detector is a modern version of the wire gas proportional counter, which has been a workhorse of X-ray astronomy for decades. Like wire counters, micropattern detectors can be designed to have large area and be sensitive to the lowest X-ray energies. In addition, they are naturally suited to applications where fine-pitch imaging is required.

In recent years, micropattern detectors have led to a resurgence of interest in X-ray polarimetry in the astrophysics and solar physics communities. X-rays, like all electromagnetic radiation, possess electric and magnetic fields that oscillate in a direction perpendicular to the X-ray's direction of motion. Astronomers have long sought to employ X-ray polarimetry to measure those directions and glean clues about the objects creating them, including black holes, neutron stars, and the structure of their surrounding fields. Polarimetry could yield information about the state of matter and acceleration of particles in extreme magnetic and gravitational fields. Much of this information is difficult or impossible to obtain by imaging, spectroscopy, or timing, which are the only other available techniques. In contrast to observations at other wavelengths, a lack of sensitive instruments has prevented X-ray polarimeters from becoming common tools in astronomy. In fact, only polarization from the Crab Nebula has been undisputedly measured, despite on-and-off-again attempts spanning nearly 40 years.

Interest in astronomical X-ray polarimetry was revitalized by the demonstration by Costa et al. in 2001 of a polarimeter based on the micropattern detector. Costa's group imaged thousands of photoelectrons, electrons ejected by an atom when it absorbs an X-ray, using a detector filled with a gaseous mixture of neon and dimethyl-ether. A photoelectron's emission direction is strongly correlated with the parent X-ray's polarization. By exposing their detector to both polarized and unpolarized X-rays and reconstructing the photoelectrons' emission angles, they showed their detector has a strong response to this effect.

This technique promises orders-of-magnitude gain in polarization sensitivity because it combines high sensitivity to the photoelectric effect, relatively high-quantum efficiency, broad energy band-pass, and imaging. A micropattern polarimeter would combine polarimetry with timing, imaging, and energy resolution. Such an instrument could eventually serve as an imaging focal plane detector for any of the large area, long focal length X-ray telescopes being studied by NASA and ESA. Combined with a rotating collimating modulator like the one on the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), a micropattern detector could be used to study magnetic fields and particle acceleration in solar flares.

Even within an Explorer-class mission, this new polarimeter concept enables powerful new scientific capabilities. In 2003, we proposed a photoelectric polarimetry mission, the Advanced X-ray Polarimeter (AXP), to NASA's Small Explorer (SMEX) program [Swank 04]. The AXP mission would be able to make sensitive polarimetry measurements of about a hundred X-ray sources. The SMEX review committee gave the AXP science its highest rating—Category One—and deemed it worthy of Explorer new technology development funding to bring photoelectric polarimetry to greater flight readiness. Our technology development efforts will conclude this year with a proto-flight photoelectric polarimeter.

Micropattern detectors are imaging proportional counters that rely on closely spaced perforated electrodes to establish the strong electric fields necessary to create ionization avalanches in gas. To make micropattern detectors, we normally perforate metallized plastic foils using the same techniques for making fine-line flexible printed circuits, photolithography, laser patterning, and chemical milling. Although the fabrication techniques are commonly available, high-quality small pixel micropattern detectors are still not readily available for purchase, due to the low demand (compared with printed circuits) and specialized "tricks" required. One purpose of this

investigation was, therefore, to maintain and expand Goddard's in-house micropattern fabrication ability.

Another goal was to make micropattern detectors that did not need plastics. Plastics outgas, and can slowly poison the gas. This problem is usually avoided by flowing gas through the detector volume. But for space-flight detectors, this is an undesirable solution because it adds failure modes and requires consumables. Another problem with plastic substrates is the difficulty in achieving good metal-plastic adhesion. Even local delamination of the metal electrode near a hole will cause breakdown and detector failure. For this reason, we proposed to develop long-lived micropattern detectors using very low outgassing materials and rugged construction techniques.

Accomplishments to Date:

We investigated two different micropattern geometries: the micromega and the Gas Electron Multiplier (GEM). A micromega has a single perforated foil suspended above a readout anode, while a GEM has two foils and a readout anode (Figure 1). Micromegas are simpler to make than GEMs, but GEMs have two features that are advantageous for some applications. The readout structure resides in a low-field region. Also, GEM readout anodes do not exhibit "ballistic deficit," a long time-scale signal due to ions created in an avalanche slowly drifting back to the cathode. This makes the GEM a suitable geometry for a time-projection chamber, which is the basis of an advanced X-ray polarimeter that we are developing.

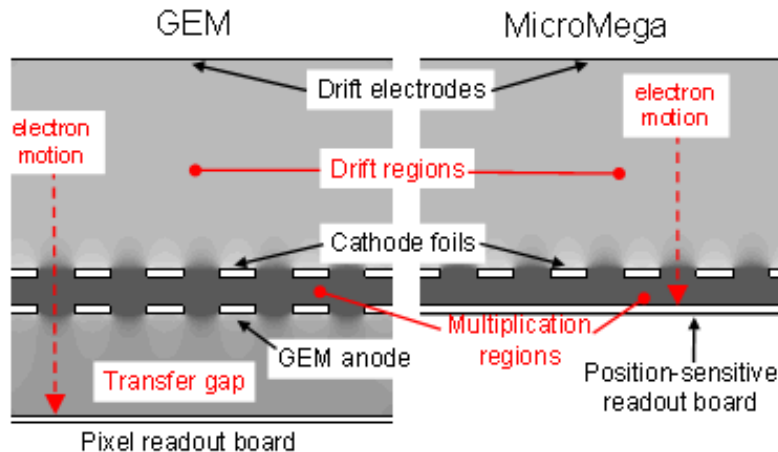


Figure 1. Two micropattern geometries, the GEM and the micromega. The active region of both geometries is the gas-filled volume between the drift electrode and the cathode. Electron avalanches occur in the high-field (darker) region.

We found that the electrodes can be successfully manufactured either by chemical etching or by electroforming. The former is more suitable for areas larger than a few hundred cm^2 , while the latter allows finer feature sizes. We purchased etched and electroformed foils with 80-micron pitch from two companies, and etched 150-micron pitch foil from a third company.

The foils are stretched and mounted on frames, either with epoxy or by welding. For assembling GEMs, we developed a technique for aligning the holes of two foils to maximize the optical transmission of the foil pair. The two frames are then clamped on either side of an insulating

spacer. The spacer could be made of glass or ceramic, but to minimize time and cost, we used easily worked polymers like Kapton and Teflon.

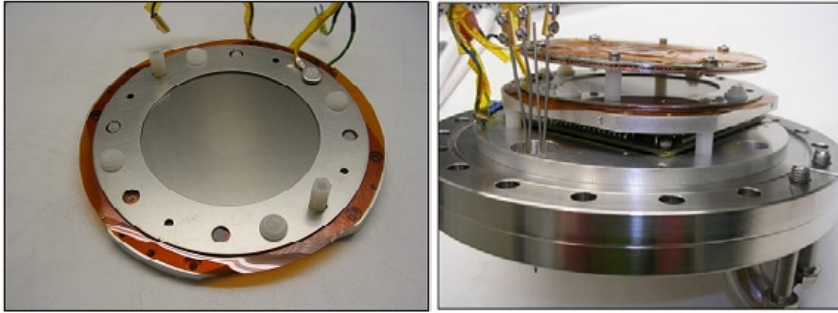


Figure 2. Left, a GEM structure. Right, the drift electrode, GEM, and an ASIC anode (hidden beneath the GEM), all mounted on a vacuum flange, ready to be assembled in a polarimeter

We successfully tested an 80-micron micromegas and 150-micron micromegas and GEMs. Our preliminary results indicate that these devices are at least as stable as micropattern detectors with plastic substrates. As an additional advantage, our micropattern detectors are free from time-dependent charging effects exhibited by plastic-substrate detectors.

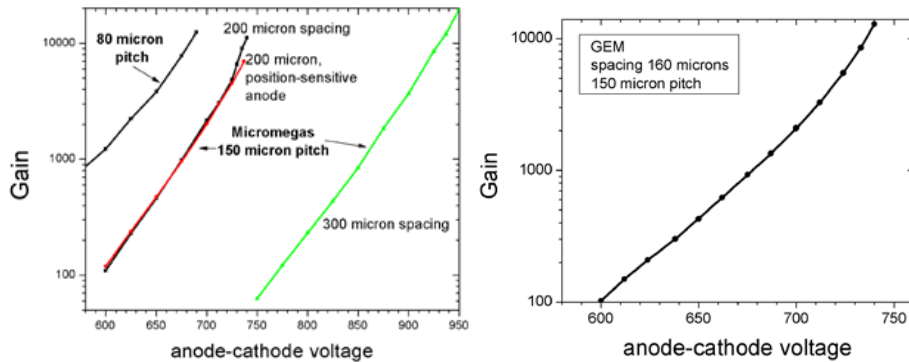


Figure 3. Typical gain curves (a) Gas gain vs. anode-cathode potential for several micromegas (b) Gain curve of a typical GEM

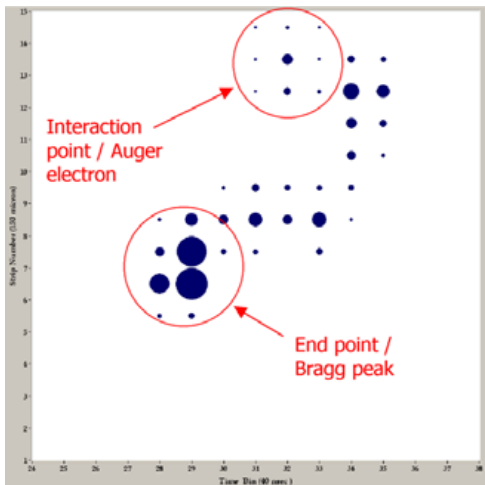


Figure 4. Image of an X-ray interaction that produced a photoelectron, taken with a polarimeter built with one of our substrate-free GEMs. Information about the polarization of the X-ray is inferred from the interaction point and direction of the photoelectron.

Planned Future Work:

Our first attempt to make an 80-micron GEM was unsuccessful, possibly because we did not mount the foils with sufficient tension for them to remain flat. This is not a fundamental problem. We expect to demonstrate an 80-micron GEM in the near future. We would like to simplify the detectors' assembly by clamping the foils together without using epoxy or welds. We also are considering a large-area X-ray polarimeter for studying solar flares. It will require detectors with larger areas.

Key Points Summary:

Project's innovative features: The project's innovation is a micropattern detector without a plastic substrate.

Potential payoff to Goddard/NASA: We have provided Goddard and NASA with a unique capability for fabricating robust, long-lived micropattern detectors suitable for astrophysics and solar physics missions.

The criteria for success: These detectors exceed our success criteria for gain and gain uniformity. (A gain of 5000 would be acceptable. We routinely exceed 10,000. A gain variation of 20% would be acceptable. Pulse height spectra indicate the gain variation must be $< \sim 10\%$).

Technical risk factors: Our proposal identified two technical risk factors. The electrodes need to be smooth, patterned with features as small as 10 microns for some applications. We demonstrated that it is possible to electroform electrodes with 40-micron diameter holes 80 microns apart, which is the finest spacing we require for any application we foresee. Also, the electrode structures must be flat and parallel to a few microns. We demonstrated that this could be accomplished with ordinary machining techniques.